

The Trauma Patient Tracking System: implementing a wireless monitoring infrastructure for emergency response

Jonathan S. Maltz¹, Thomas S.C. Ng¹, Dustin J. Li¹, Jian Wang¹, Kang Wang¹, William Bergeron², Ron Martin² and

Thomas F. Budinger¹

Department of Functional Imaging,

Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720¹

Triton Systems, Inc. 200 Turnpike Road, Chelmsford, MA 01824²

jon@eecs.berkeley.edu

Abstract—In mass trauma situations, emergency personnel are challenged with the task of prioritizing the care of many injured victims. We propose a trauma patient tracking system (TPTS) where first-responders tag all patients with a wireless monitoring device that continuously reports the location of each patient. The system can be used not only to prioritize patient care, but also to determine the time taken for each patient to receive treatment. This is important in training emergency personnel and in identifying bottlenecks in the disaster response process. In situations where biochemical agents are involved, a TPTS may be employed to determine sites of cross-contamination. In order to track patient location in both outdoor and indoor environments, we employ both Global Positioning System (GPS) and Television/ Radio Frequency (TVRF) technologies. Each patient tag employs IEEE 802.11 (Wi-Fi)/TCP/IP networking to communicate with a central server via any available Wi-Fi basestation. A key component to increase TPTS fault-tolerance is a mobile Wi-Fi basestation that employs redundant Internet connectivity to ensure that tags at the disaster scene can send information to the central server even when local infrastructure is unavailable for use. We demonstrate the robustness of the system in tracking multiple patients in a simulated trauma situation in an urban environment.¹

Keywords—biomonitoring, trauma, emergency, wireless monitoring

I. INTRODUCTION

Disaster scenarios present many obstacles to a successful coordinated rescue response. A practical way to improve the execution of emergency response activities is to provide response coordinators with real-time information that facilitates immediate assessment of the

scope of a disaster. This information can be used to determine how resources should best be allocated in order to save as many lives as possible. Unfortunately, communication of such information in disaster areas is often hampered by damage to the local infrastructure. A robust wireless information system could thus play an important role in improving trauma response [1].

Many competing wireless technologies aim to provide monitoring of the location and physiological status of individuals. Most commercial systems combine GPS and cellular telephone technology to determine the location of a subject. For example, Wherify Wireless, Inc. offers a system consisting of a wearable GPS locator that transmits data over a CDMA 1900 MHz network [2]. GeoSentry Inc. develops small mobile units that transmit GPS data over GSM networks. A web-based interface allows the visualization of tracking devices [3]. In the TPTS application, situations will arise whereby cellular phone networks are unavailable or too congested to provide data transport. Network infrastructures such as phone towers may have been destroyed in the disaster. A cellular network may not exist in the region concerned. In urban environments, reliable GPS signals may not be available due to the presence of buildings that obscure the positioning satellites.

This paper describes our implementation of a TPTS. The system is unique in that it combines GPS and TVRF location technologies and does not rely on a single communication network. It can also integrate easily with existing local tracking systems such as the wOz system produced by Wheels of Zeus, Inc. [4]. Reliability is increased by using basestations that connect to more than one network infrastructure. The system is mobile and easy to deploy. It was tested in a simulated disaster scenario to prove the viability of the TPTS concept.

II. SYSTEM DESIGN

A. Location technology

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Two technologies are used to gather positional information. GPS determines location through the triangulation of radio signals from satellites deployed in space. Satellite transmission lag time is used to determine the distance between a satellite and the receiver [5]. Multiple distance measurements are combined to make a precise location determination.

For accurate positional information, a GPS receiver requires line-of-sight reception from at least 4 satellites. In most outdoor environments, this requirement is easily satisfied. However, in urban areas, GPS signals are often very weak. Indoors, reception is almost impossible unless the receiving antenna is situated close to a window. Since it is very likely that a TPTS will be deployed in urban areas and inside buildings, one cannot rely solely on GPS location technology.

To overcome this, we incorporated TVRF location technology developed by Rosum Corporation. In the Rosum system, synchronization signals from local digital TV channels are employed to obtain position information [6]. Owing to relatively low carrier frequency ($\approx 500\text{MHz}$), large bandwidth ($\approx 6\text{MHz}$) and high signal strength ($\approx 1\text{MW}$), TV signals, and hence location fixes, may be obtained indoors.

B. *Wireless technology*

We chose IEEE 802.11 (Wi-Fi) wireless networking to connect the tag to local basestations. Employing Wi-Fi allows us to:

1. Utilize existing Wi-Fi access points as well as dedicated basestations.
2. Encrypt tag information using existing hardware and software. This is important to maintain security and privacy.
3. Easily extend the range by using repeaters.
4. Communicate bidirectionally between server and tag for maintenance, remotely initiated biomonitoring and two-way voice communication.

C. *Networking transport and routing technology*

TCP/IP networks were specifically designed to be robust in the face of partial damage to the infrastructure. We chose to employ these protocols for communication between the patient tags and the central server to leverage this robustness. Each tag directs all data packets to the IP address of the central server. As a consequence, as long as an Internet connection is available to a basestation (via Ethernet, Wi-Fi, GPRS or satellite data service), the tag and server can interact seamlessly in a network-independent manner.

We are also able to exploit the availability of existing client-server TCP/IP applications to perform remote maintenance and control of the tag.

III. SYSTEM IMPLEMENTATION

The 3 major components of the TPTS are the wearable tag, the basestation and the tracking server.

A. *Wearable Tag*

The wearable tag is secured to patients and/or ground crew members at the accident scene. The minimum TPTS tag specifications for our prototype implementation were:

1. GPS/TVRF location capabilities.
2. Minimum line-of-sight range of 100m between tag and basestation.
3. Minimum battery life of 6 hours.
4. When out of range of a basestation, the tag should internally log its positional history and upload this to the server when connectivity is restored.

For our TPTS we employ the Sharp Zaurus SL-6000 Personal Digital Assistant [7] as the tag prototype (Figure 1). This offers the following advantages:

1. Integrated 802.11 connectivity and flexible device drivers.
2. Convenient Intel Xscale/StrongARM-based Linux development platform provides inexpensive tools for hardware manipulation and rapid software development as well as access to a large online community for technical support.
3. Two peripheral ports (serial and Compact Flash) for the convenient attachment of sensors.
4. A Secure Digital interface that allows a large amount of data to be stored on memory cards.
5. Binary code and operating system compatibility with very low power wearable computers such as the Gumstix [8] Intel XScale/StrongARM platform.
6. Tag "talk-time" (TTT) can be extended using standard Li-ion batteries.

A Compact Flash GPS card (Ambicom Inc.) provides the Zaurus with streaming latitude, longitude, altitude and time information. The data are stored and then transmitted to a central server through an Internet connection via the 802.11 wireless card. The Zaurus continuously searches its locale for networks, connects to one of these networks and then uploads positional data to the server. Each Zaurus contains a list of preferred registered networks such as those of known mobile and hospital basestations. Where none of the preferred networks is available, connection is made through any available wireless access point. When no networks are available, the internal log queues position information for later transmission or direct transfer from the memory card.

Power is an important consideration that can preclude real-time data streaming to the central server. The Zaurus' internal power source was augmented with 1750mAh Li-ion batteries, increasing the TTT from 3 hours to over 7 hours.

B. *Mobile basestation*

While each tag can utilize any 802.11 basestation, it is not sufficient to assume that such an infrastructure

exists, especially in a disaster situation. To ensure tag connectivity, first-responders install mobile basestations at the disaster scene, effectively creating an instant infrastructure. Basestations are also fitted to emergency vehicles such as ambulances. In this way, patients near or within these vehicles may be monitored during transit.



Fig. 1. Top shows the mobile basestation with components labeled: A) Laptop, B) Bluetooth enabled cellular phone with GPRS service, C) PCMCIA GPS card, D) GPS Antenna, E) Wireless access point antenna, F) Wireless access point, G) Satellite phone with data service. Bottom shows the Zaurus patient tag with GPS card attached.

Our prototype basestation (Figure 1) employs a Linux-based notebook PC to route incoming tag data (from an attached wireless access point) to the server using the best available network connection. The basestation can connect to the Internet in 4 ways, in decreasing order of priority:

1. Wired Ethernet
2. 802.11b/g wireless Ethernet
3. Cellular General Packet Relay Service (GPRS)
4. Satellite packet radio service

The GPRS connection is achieved via a PPP/RFCOMM/Bluetooth connection to a mobile phone (Sony Ericsson T68i) while PPP satellite data service is provided by the GlobalStar network via a wired serial connection to a Qualcomm GSP 1600 satellite phone.

The basestation constantly monitors the viability of a TCP/IP connection to the server. If such a connection is presently unavailable, the basestation attempts to bring up a connection of lower priority. When a functional connection is available, the basestation will attempt to establish a “better” connection on the basis of priority. In this way, the basestation continually establishes the best available path for the transport of tag data.

In most situations, one of the four connection options will be viable. Wi-Fi and GPRS networks are prevalent in

urban areas. Satellite phone coverage spans a large portion of the world’s continental land mass [9].

To allow coordinating personnel to monitor the current locations of field basestations and emergency vehicles, each basestation is outfitted with a PCMCIA GPS card (Ambicom GPS CF). The basestation then communicates this information to the central server in the same manner as a tag.

C. Central server

Finally, a central server stores and processes the data from the tags and basestations. The server allows users to visualize the status of basestations, patients and emergency personnel in real time.

A useful TPTS must provide a visualization interface that concisely conveys all the information needed for managing a trauma situation. Present and former locations of tags and basestations should be clearly displayed on topographical maps and aerial photographs of the disaster scene. The locations of places such as hospitals should also appear.

Several programs are currently available to plot positional data on a map. GpsDrive is an open-source Linux program that reads NMEA data off a GPS device to create a map of the surrounding area [10]. GPSVisualizer.com performs mapping functions with user-uploaded text files as input [11]. Although these tools are well-designed, none provides the specific features that a TPTS requires. In order to satisfy these requirements, we developed our own visualization program, TagView.

Using all available track information, TagView generates a map that is scaled to contain each tag’s current and previous locations. The user is then able to zoom-in to any area of interest. Clicking on a track point allows the user to determine the name of the reporting tag and the time at which that location was reported.

TagView is extremely flexible as it is able to download correctly scaled maps of any region in the world using online map repositories such as Expedia.

Track histories from different tags are plotted using different colors. The color intensity of each patient plot point changes with respect to the time stamp. Older points have darker color intensities. This color scheme imposes time-directionality on each patient’s track. To achieve almost real time plotting, the program constantly checks for any new data available from the central server and updates the map accordingly.

IV. SYSTEM DEMONSTRATION

The TPTS was tested in a 25km² area of Berkeley, California that included the University of California (UC) campus and the Alta Bates Medical Center. This constituted a challenging environment for the TPTS owing to the hilly topography, presence of large buildings and poor cellular network coverage. We monitored the location of ambulatory subjects, subjects within vehicles and the vehicles themselves. All subjects were tracked from a common starting point (the simulated disaster

zone) on the UC campus. We now describe the routes of the four subjects (Figure 2).

A. Subject 1

This subject walked out of basestation connection range at the disaster site and was picked up approximately 1km north of his initial position by an ambulance that contained a mobile basestation. He was transported to Alta Bates Summit Medical center. Our tags were programmed to recognize the 802.11 infrastructure at this hospital and connect to it when within range.

B. Subjects 2 and 3

These subjects walked together from the disaster site to a basestation-equipped campus hospital (University Health Services, Tang Center) in order to compare the abilities of GPS and TVRF in an urban environment. The route involved walking through large campus buildings with poor access to GPS signals.

C. Subject 4

The fourth subject was picked up by an ambulance directly at the disaster site and brought to a simulated medical center at Lawrence Berkeley National Laboratory. This medical center was equipped with a wireless infrastructure to which the tag was programmed to connect.

As the four subjects moved, their positions were uploaded when there was an available network connection or archived until a successful transmission could take place.

V. RESULTS

Figure 2 illustrates the tracks of the four patients. The track coordinates plotted on the map are consistent with predetermined routes that the subjects were instructed to follow. However, there are instances where the tags lost their GPS fixes. An example appears in the track of Subject 3 shown in Figure 3 where no data points are available while this patient walked through campus buildings.

The TVRF receiver was not quite as accurate as the GPS devices. While it acquired a signal in indoor areas where GPS could not (as indicated by the orange plot points), it was not accurate enough to convey to the observer that the patient was walking through the building. In addition, the rate of transmission was more limited than that of the tags equipped with GPS receivers owing to limitation of the TVRF prototype provided by Rosum.

Caching of data points was successful as evidenced by the complete tracks of those subjects that were all without a network connection between the times that they lost local basestation coverage and the times that they reached a hospital or a basestation-equipped ambulance.

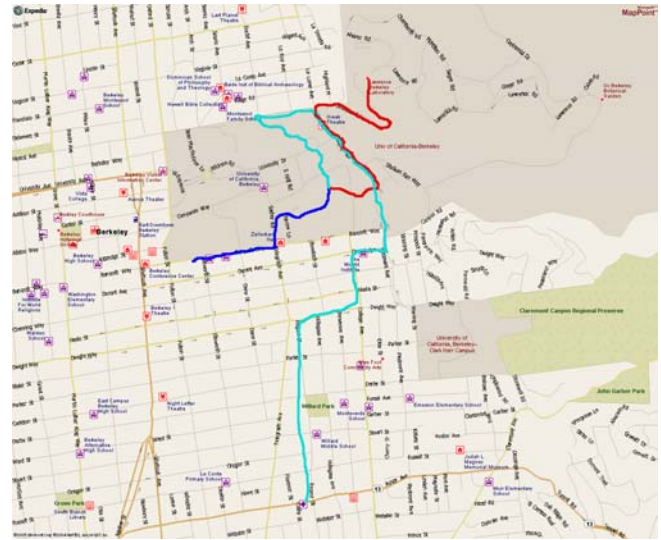


Fig. 2. Pre-determined routes for TPTS demonstration. Cyan is Subject 1, Blue is Subjects 2 and 3, Red is Subject 4.

VI. CONCLUSION

Our TPTS implementation was successful in that it met all of the design specifications and performed according to our expectations in a reasonably realistic test scenario. Our demonstration revealed the limitations of GPS-only positioning for TPTS tags and showed how supplementation with TVRF technology can increase robustness. Although this developmental technology was not as accurate as GPS, it is useful when no GPS signal is available.

In the event of TV signal broadcasts being compromised during a disaster, the TPTS can be integrated with the wOz system to form a localized tracking network. Alternatively, Rosum can supply dedicated transmitters to provide a positioning infrastructure over a large area.

Our prototype system did not include biomonitors instrumentation. However, devices that measure the pulse, electrocardiogram, blood oxygen levels and blood pressure can be easily incorporated into the tag. The availability of the short medical history of the patient between attachment of the tag and administration of medical care may expedite the delivery of appropriate care. The bidirectional communication architecture is particularly attractive from the point-of-view of remotely initiating physiological measurements. It is also possible to establish verbal communication with the patient.

Miniaturization of all aspects of the monitoring system would facilitate its deployment and use. We have explored several networking and computing platforms, such as the Gumstix [7] wearable computer and Moteiv wireless transceiver (mote) [12]. The latter could extend the tag-to-basestation range, since it utilizes IEEE 802.15 low-power self-organizing ad-hoc network technology. The ability of these networks to adaptively route packets between nodes offers increased robustness and extended range. Networks of an older generation of motes

integrated with structural engineering sensors have already been tested in critical applications [13].

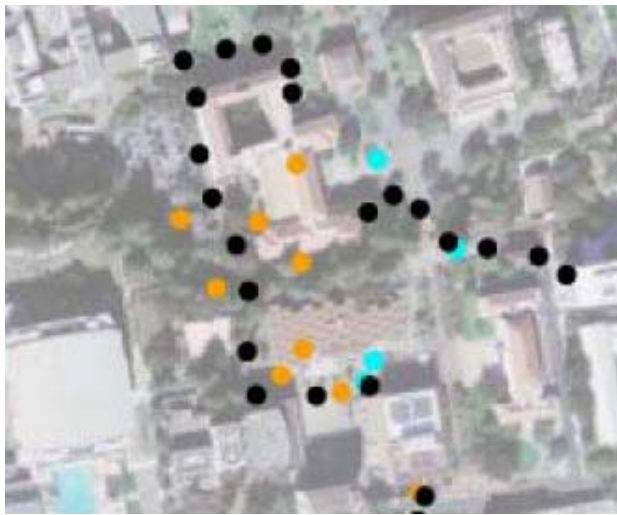


Fig.3. Comparison of GPS (Black points) versus TVRF (Orange points) technology. Note TVRF signal is discernable while in the building, while the GPS signal is not.

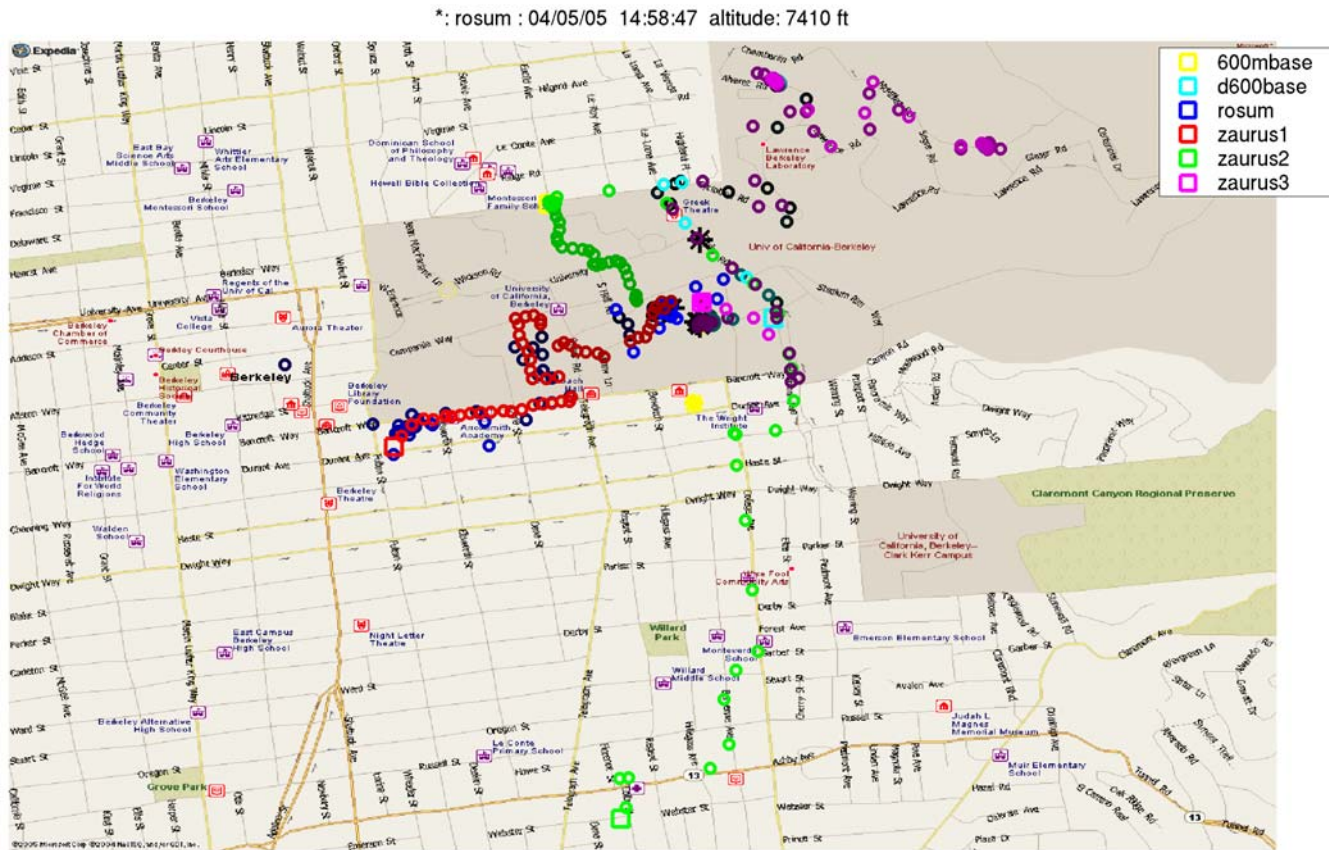


Fig.4. TagView display of the demonstration. Green is Subject 1, Blue is Subject 2 (TVRF), Red is Subject 3 (GPS), Purple is Subject 4.

As with all systems that transfer sensitive data, security and authenticity of data needs to be addressed. This was not emphasized in the TPTS proof-of-concept prototype. Future development upon the TPTS model would need to incorporate encryption methods for data transfer. Again, we can leverage existing technology to

make the implementation of a secure TPTS almost seamless. Once a viable connection is established, Secure Sockets Layer (SSL) can be used to encrypt the information uploaded to the central server.

Future work will involve the integration of biomonitoring sensors, the miniaturization of all aspects of the system and integration of TVRF onto each tag.

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